

Using Future Climate Projections to Support Water Resources Decision Making in California

Sixth Annual 2009 Climate Change Symposium

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Bay-Delta Office



HYDROLOGY

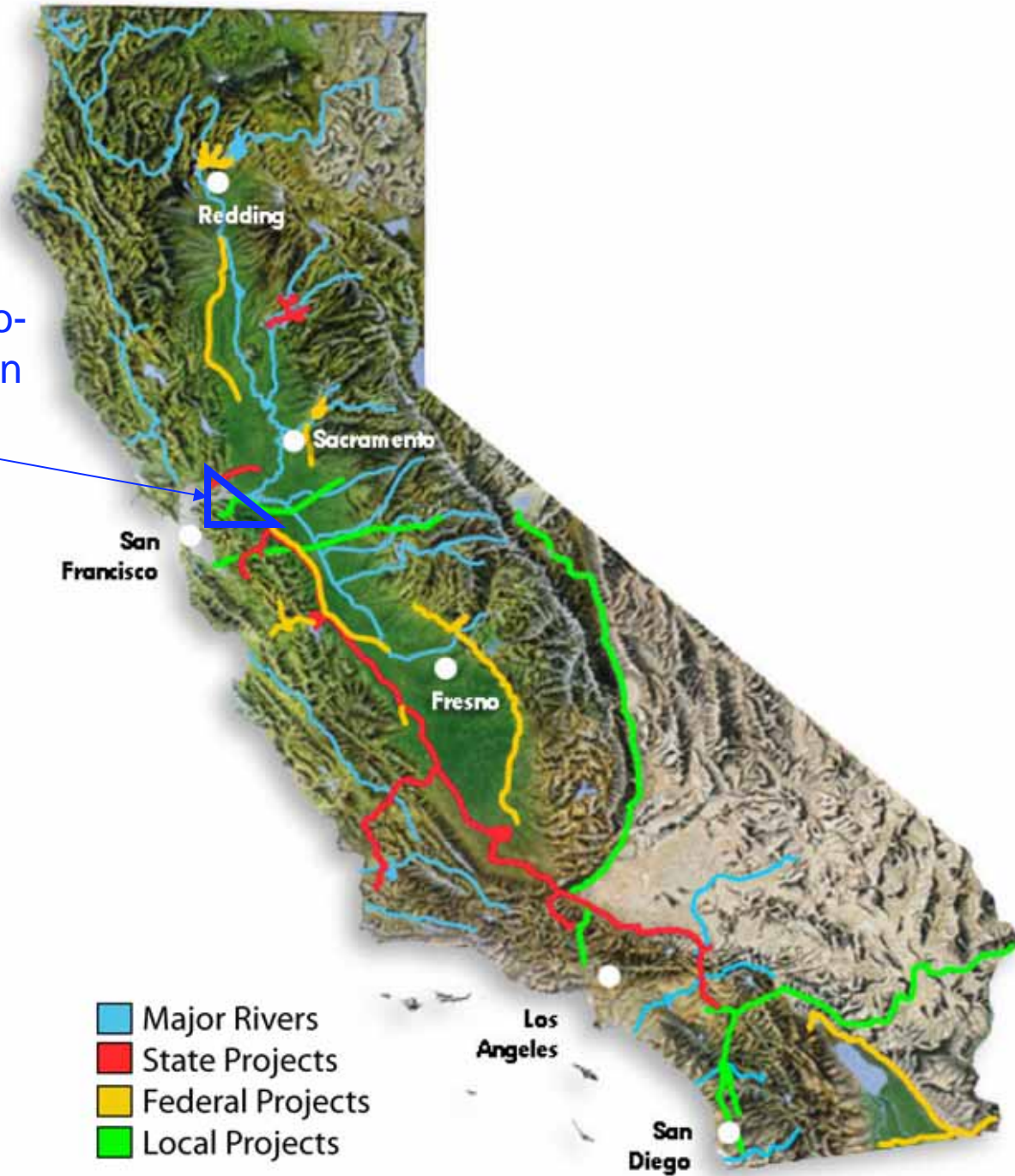
Annual Precipitation

(Year 2005)

in millimeters



Sacramento-
San Joaquin
Delta



Increases in very high temperatures will have wide-ranging effects.

Number of Days Over 100°F

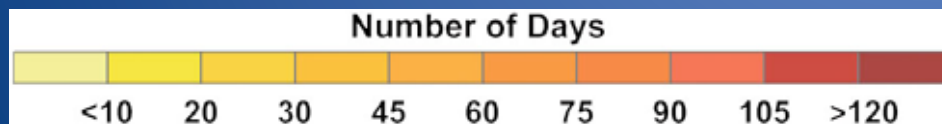
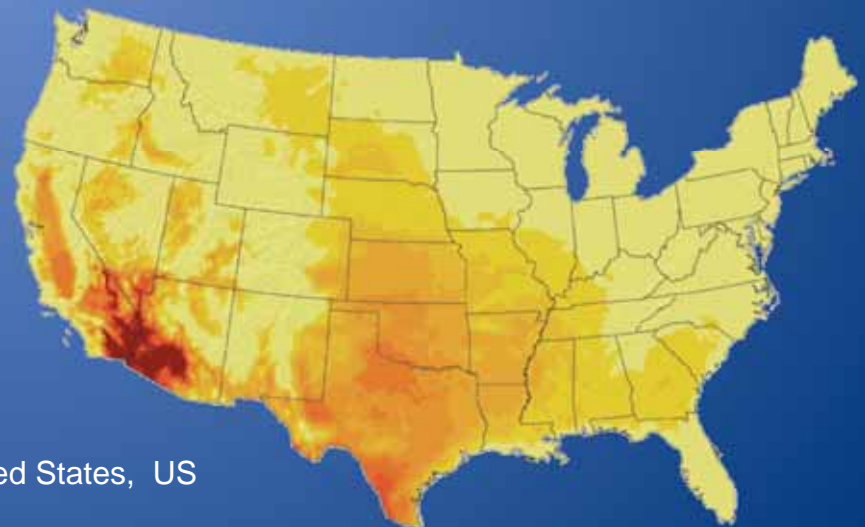
Recent Past, 1961-1979



Higher Emissions Scenario, 2080-2099



Lower Emissions Scenario, 2080-2099

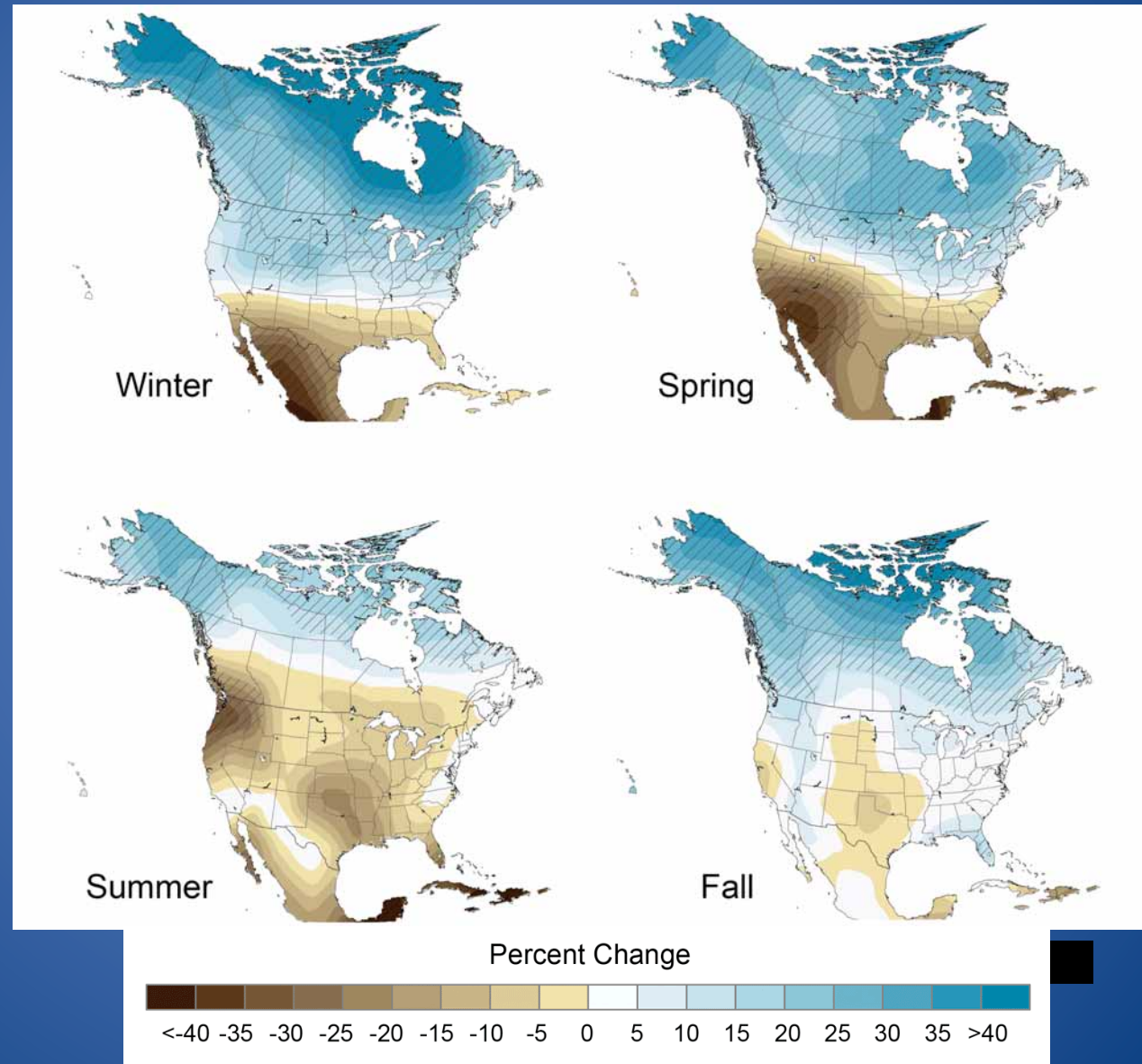


From "Global Climate Change Impacts in the United States, US Global Change Research Program, June 2009"

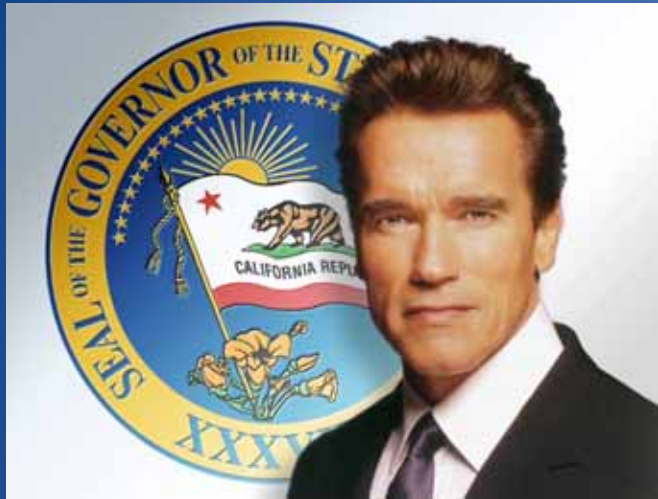
Water resources will be affected by changing precipitation patterns and increasing temperatures.

Projected Change in Precipitation by 2080-90s

From "Global Climate Change Impacts in the US, US global Change Research Program, June 2009"



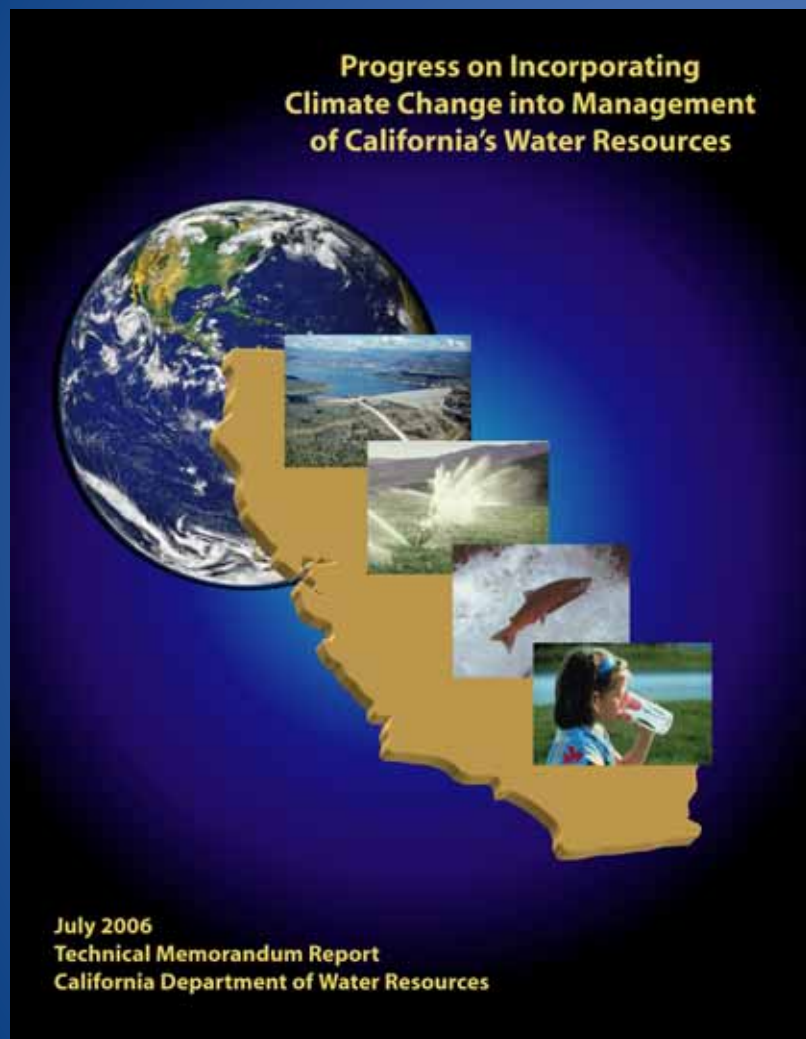
Governor's Executive Order S-3-05



- Signed June 1, 2005
- Targets to reduce emission levels of greenhouse gases
- Required biennial reports starting January 2006
 - Water supply
 - Public health
 - Agriculture
 - CA coastline
 - Forestry
- Formed Climate Action Team

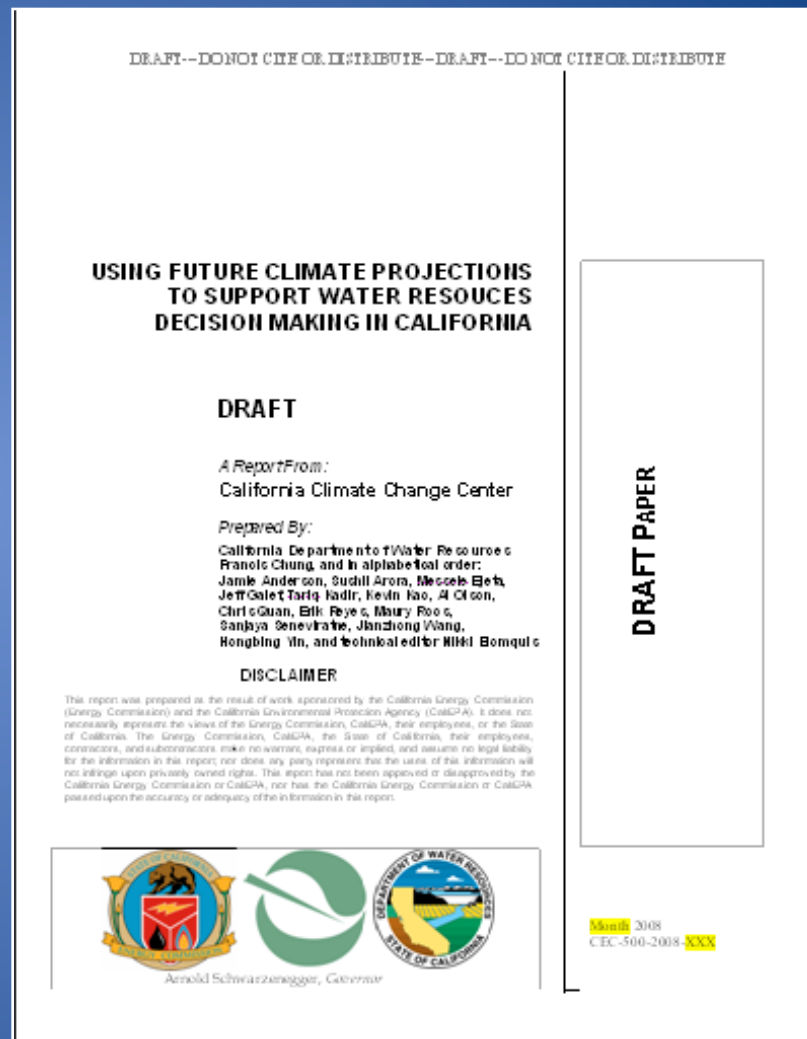
2006 Report

4 Scenarios (2 GCM x2 GHG)



2009 Report

12 Scenarios (6 GCM x2 GHG)



Acknowledgements

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- Jianzhong Wang
- Hongbing Yin
- Nikki Blomquist



2009 CAT Future Climate Scenarios

6 Global Climate Models

- GFDL-CM2.1 (USA)
- NCAR-PCM1 (USA)
- CNRM-CM3 (France)
- MPI-ECHAM5 (Germany)
- MIROC3.2med (Japan)
- NCAR-CCSM3 (USA)

2 GHG Emissions Scenarios

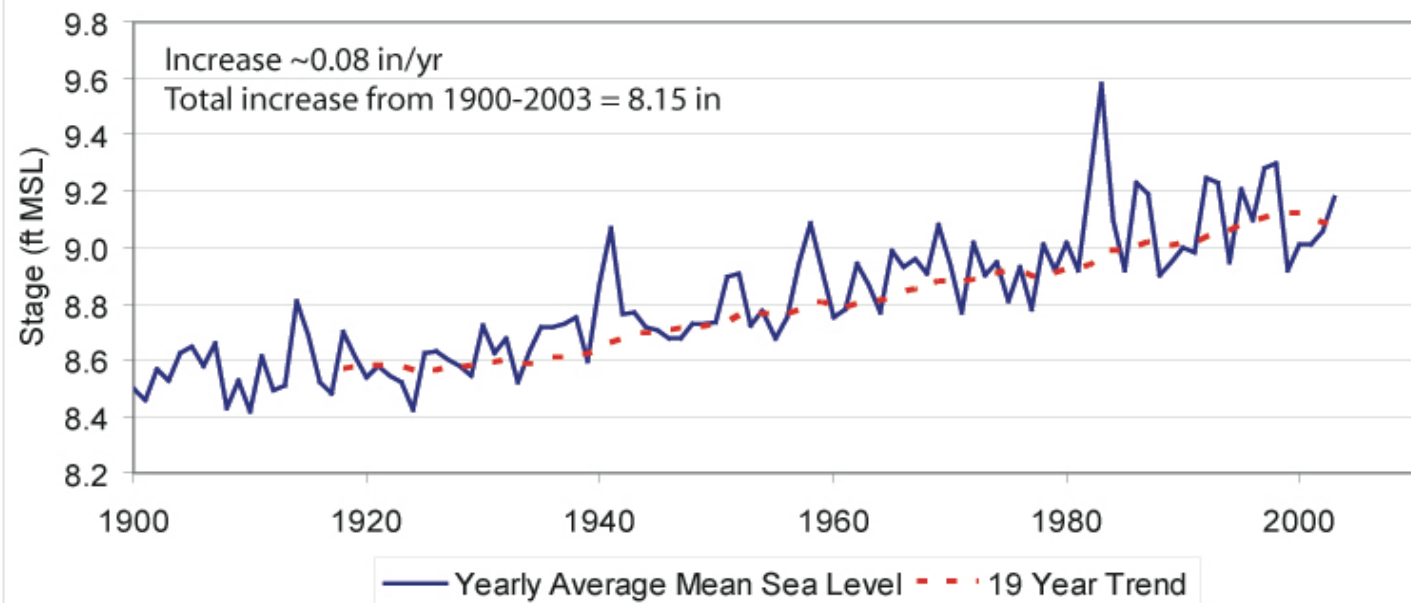
- A2 (higher GHG emissions)
 - high population growth
 - regional economic growth
 - fragmented technological changes
- B1 (lower GHG emissions)
 - low population growth
 - rapid economic growth
 - sustainable technology


12 Total Scenarios = 6 GCM x 2 GHG Emissions Scenarios

Using Future Climate Projections in Decision Making

- Sea level rise
- Effects of increasing air temperature on the upper Feather Basin
- Climate change impacts on water supply reliability

Sea Level Rise



A seagull is flying in the upper left corner of the image. Below it, a massive, curling ocean wave dominates the center of the frame. The water is a deep blue, and the wave's crest is white with foam. In the bottom right, a cartoon woman in a purple dress is walking on the beach, holding an orange and white life preserver. The overall scene is a dramatic illustration of rising sea levels.

The Sea is Rising!

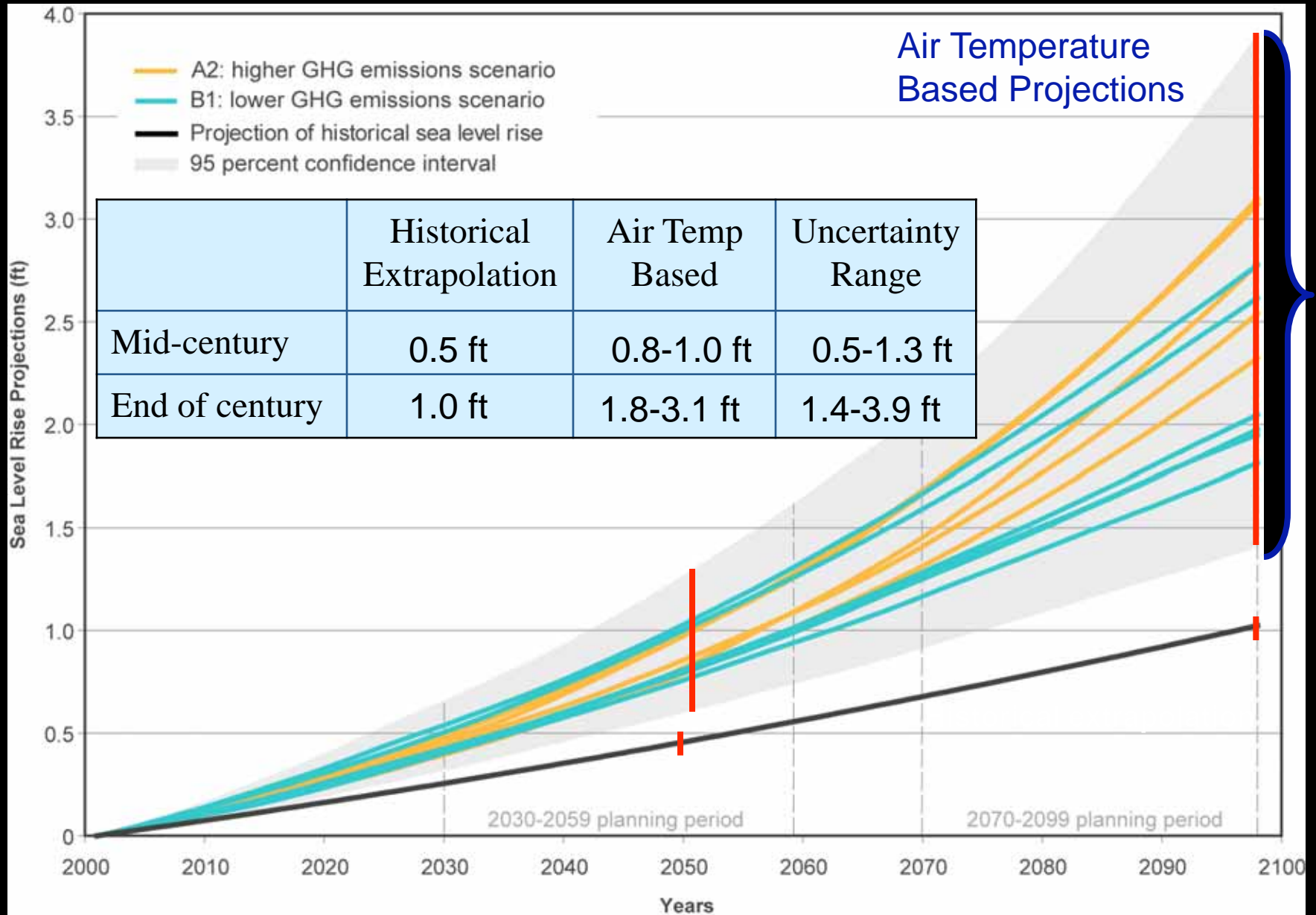
How much will sea level rise?

What is the likelihood that sea levels will rise by a certain amount?

How do I plan for it?

How can we represent sea level rise effects on Delta salinity in computer models?

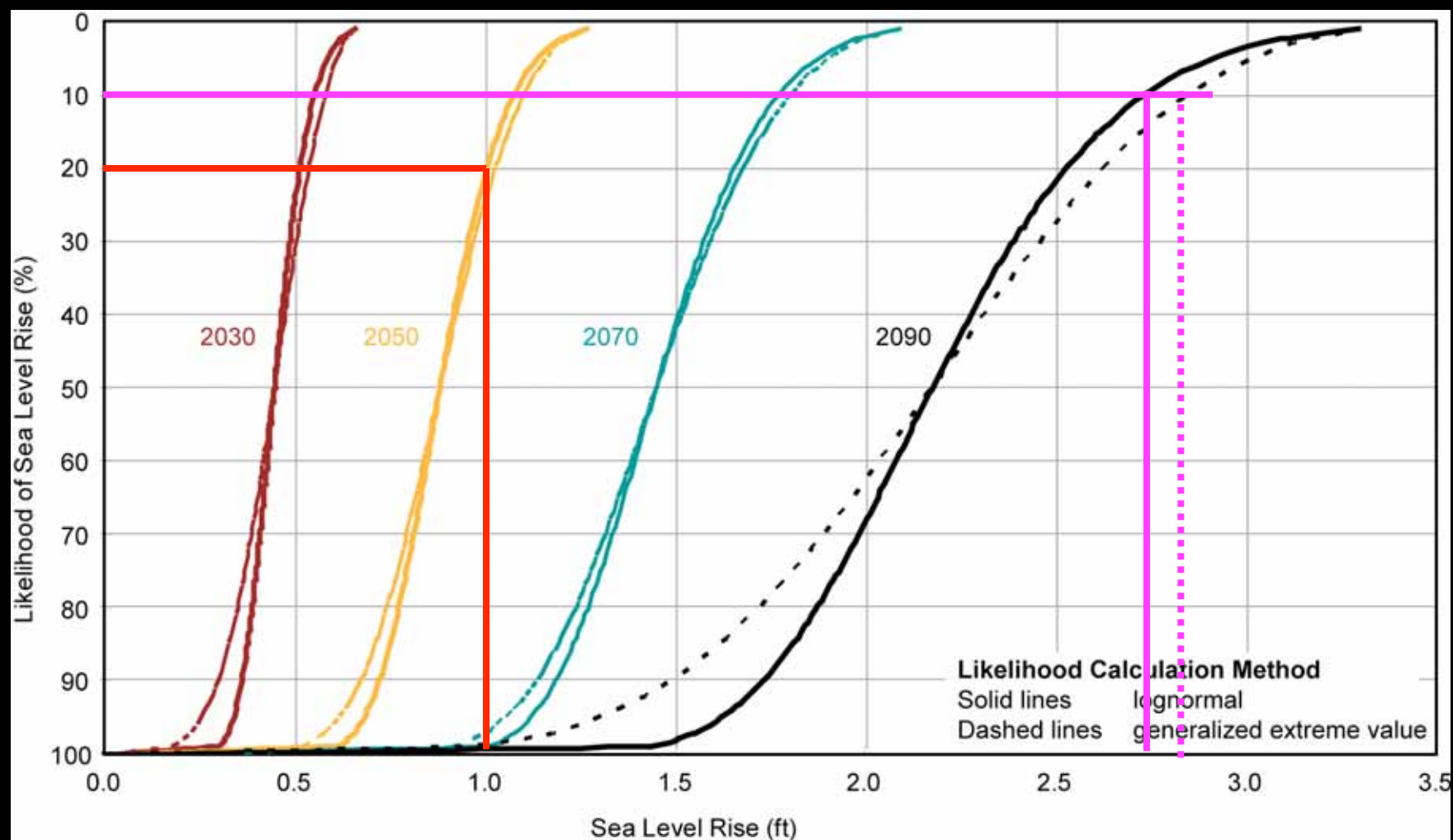
Air Temperature Based Projections



Relative Likelihood from 12 Scenarios

2050 20% chance 1ft SLR

2090 10% chance SLR 2.75-2.80ft



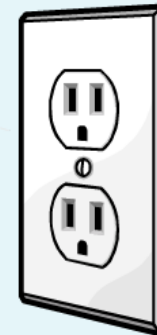
Models of SWP and CVP Operations Need a Way to **Quickly** Represent Delta Water Quality Standard Compliance

Sea Level Rise Artificial Neural Networks

Sacramento-
San Joaquin
Delta



+



=



Sea Level Rise
ANN

Management Tool
(e.g. CalSim, CalLite)

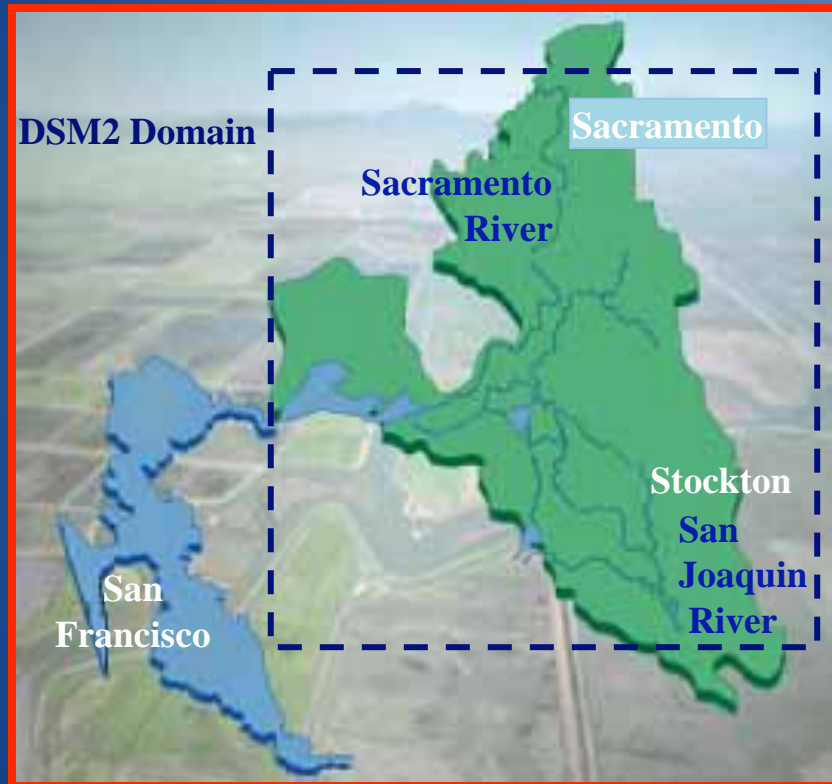
SLR Impacts on
Water Projects

A Delta salinity ANN is a computer program that quickly estimates Delta salinity based on inflows and exports

An ANN can be used in management tools such as CalSim and CalLite to estimate sea level rise impacts

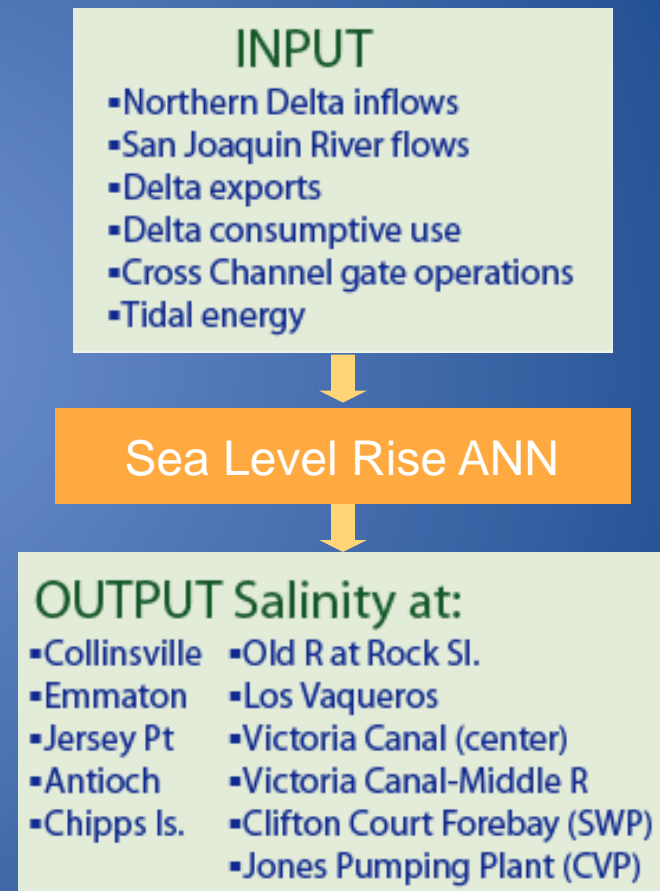
Developing Delta Salinity ANNs

1. Use DSM2 to simulate Delta Salinity for SLR scenarios



- Increase water level at Martinez
- Increase salinity at Martinez based on DRMS study by Ed Gross

2. Using DSM2 results, “train” SLR ANN to replicate Delta salinity based



Non-stationarity in Changing Climate

Stationarity is Dead

Milly et al, SCIENCE, 2006

Finding a suitable successor is crucial for human adaptation to changing climate.

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,^{1*} Julio Betancourt,² Malin Falkenmark,³ Robert M. Hirsch,⁴ Zbigniew W. Kundzewicz,⁵ Dennis P. Lettenmaier,⁶ Ronald J. Stouffer⁷

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year-periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.\$50 billion (1).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (2, 3). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

¹U.S. Geological Survey (USGS), c/o National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA. ²USGS, Tucson, AZ 85745, USA. ³Stockholm International Water Institute, SE 11351 Stockholm, Sweden. ⁴USGS, Reston, VA 20192, USA. ⁵Research Centre for Agriculture and Forest Environment, Polish Academy of Sciences, Poznań, Poland, and Potsdam Institute for Climate Impact Research, Potsdam, Germany. ⁶University of Washington, Seattle, WA 98195, USA. ⁷NOAA, Geophysical Fluid Dynamics Laboratory, Princeton, NJ 08540, USA.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (4, 5) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (6). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (7).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (8), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability

that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (9) and water supply (10) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (11, 12). Accounting for the substantial uncertainties of climatic parameters estimated from short records (13) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (12, 14).

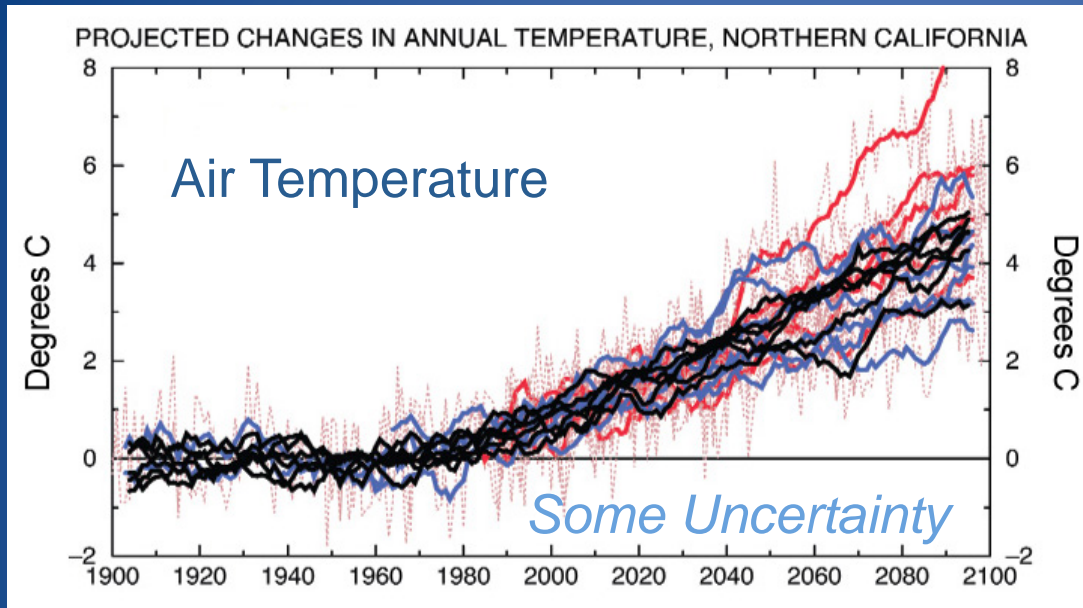
Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (15). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (16), although attempts to detect a recent change in global flood frequency have been equivocal (17, 18). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (19). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO₂ and the thermal inertia of the Earth system (4, 20).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (21, 22), the assumption of stationarity was

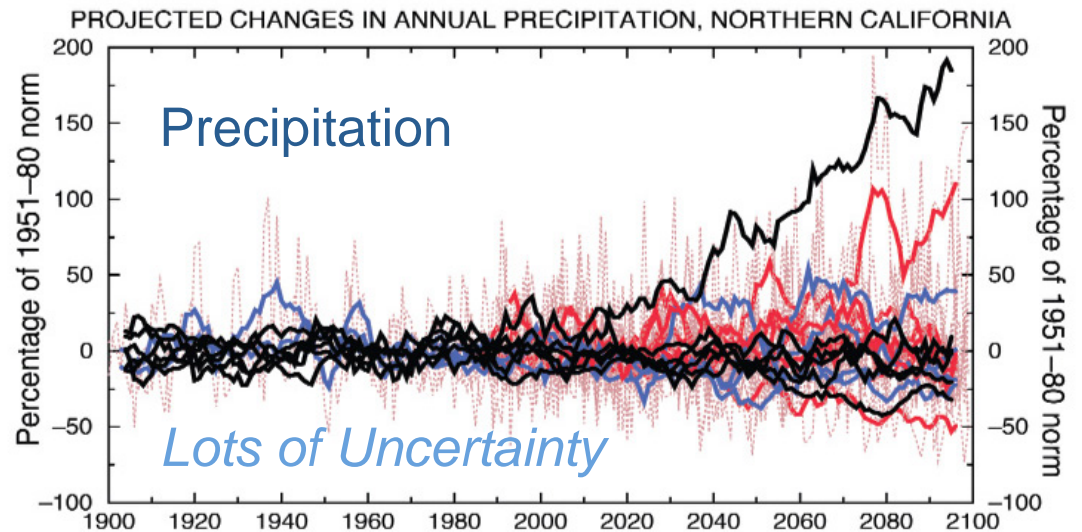
Climate Projections for California



Temperature is increasing

Precipitation patterns uncertain

Based on IPCC Scenarios
From Dettinger, 2005

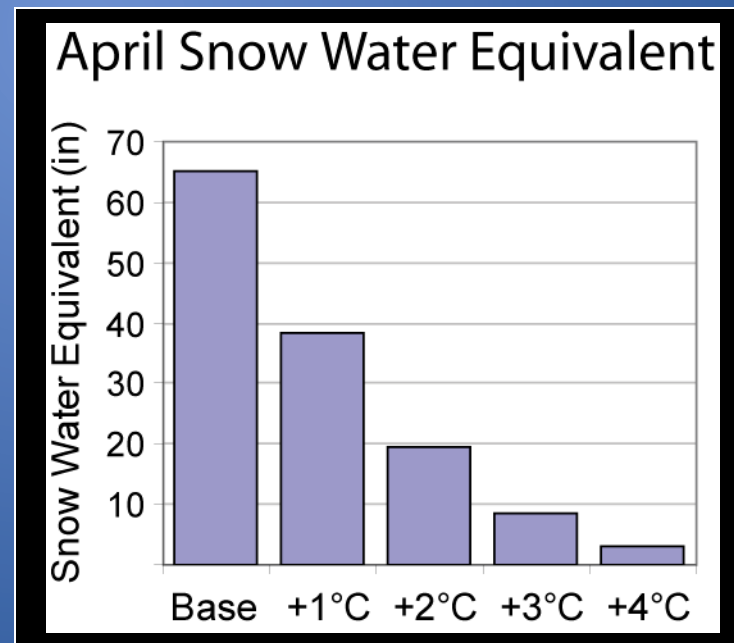


Feather River Basin: California's State Water Project Origin

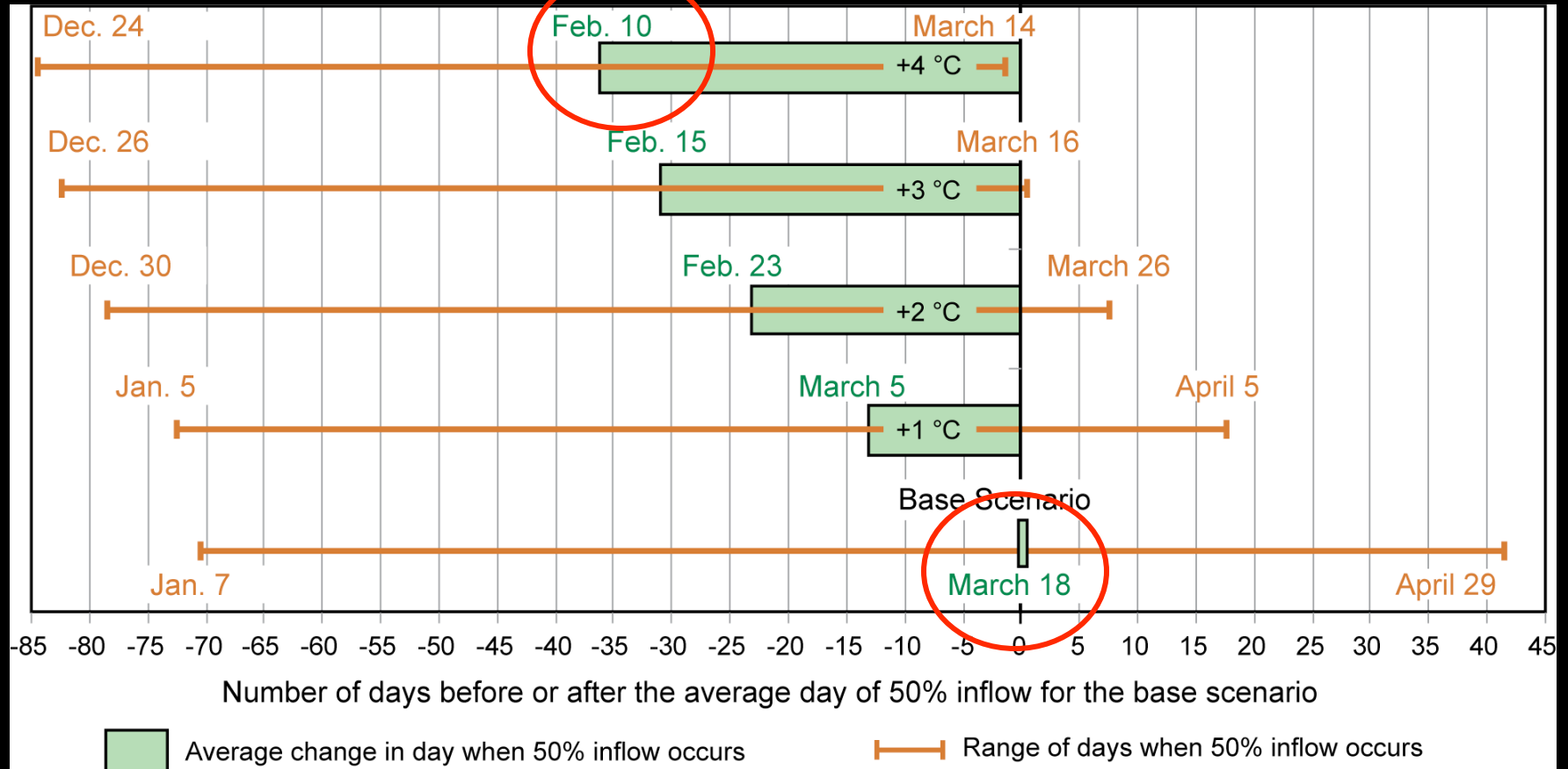


Upper Feather River Basin

- Inflow to Lake Oroville
- Effects of rising air temperature
 - Precipitation-runoff model PRMS
 - +1°C, +2°C, +3°C, +4°C

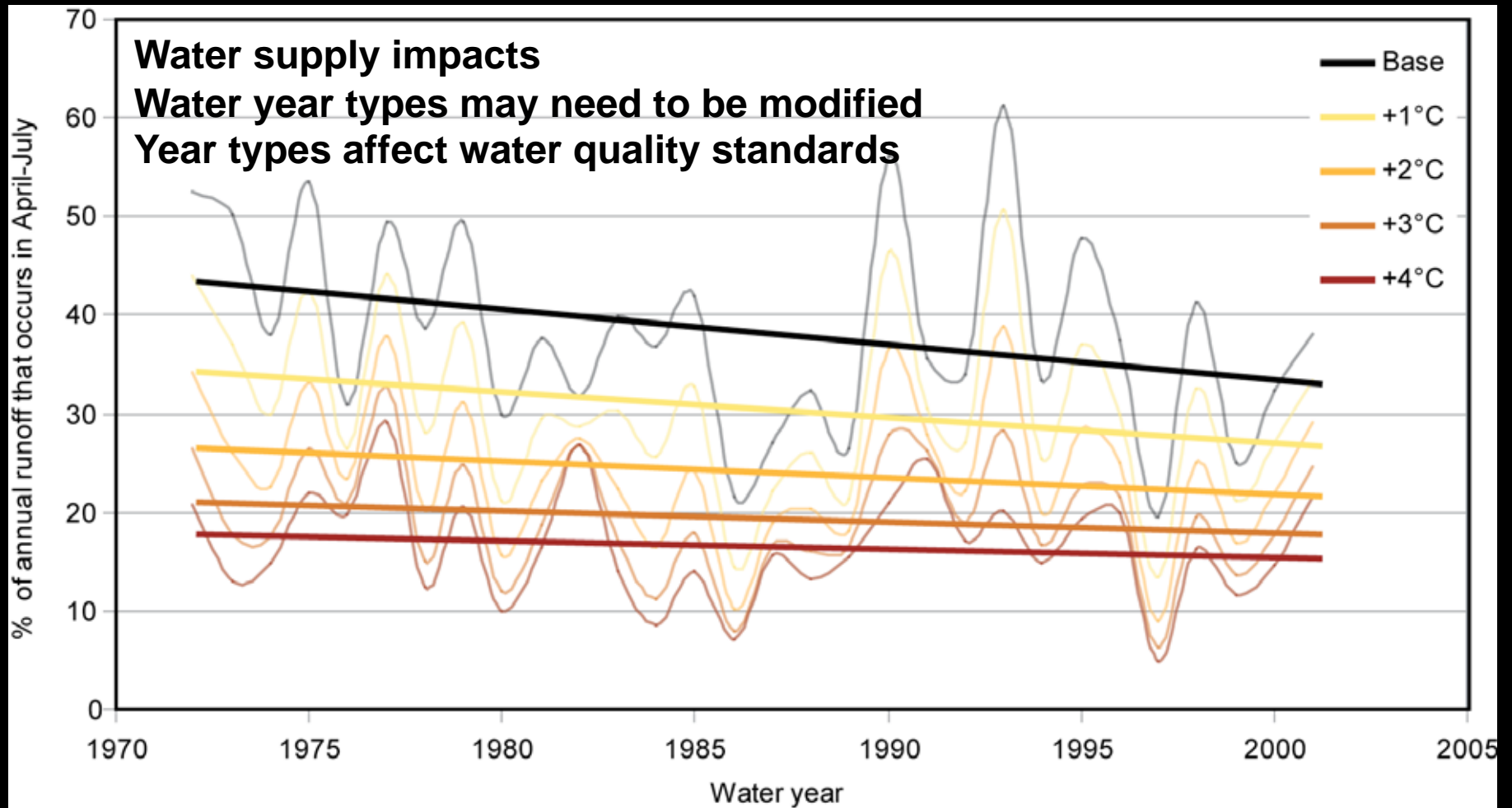


Day of 50% Annual Inflow at Oroville



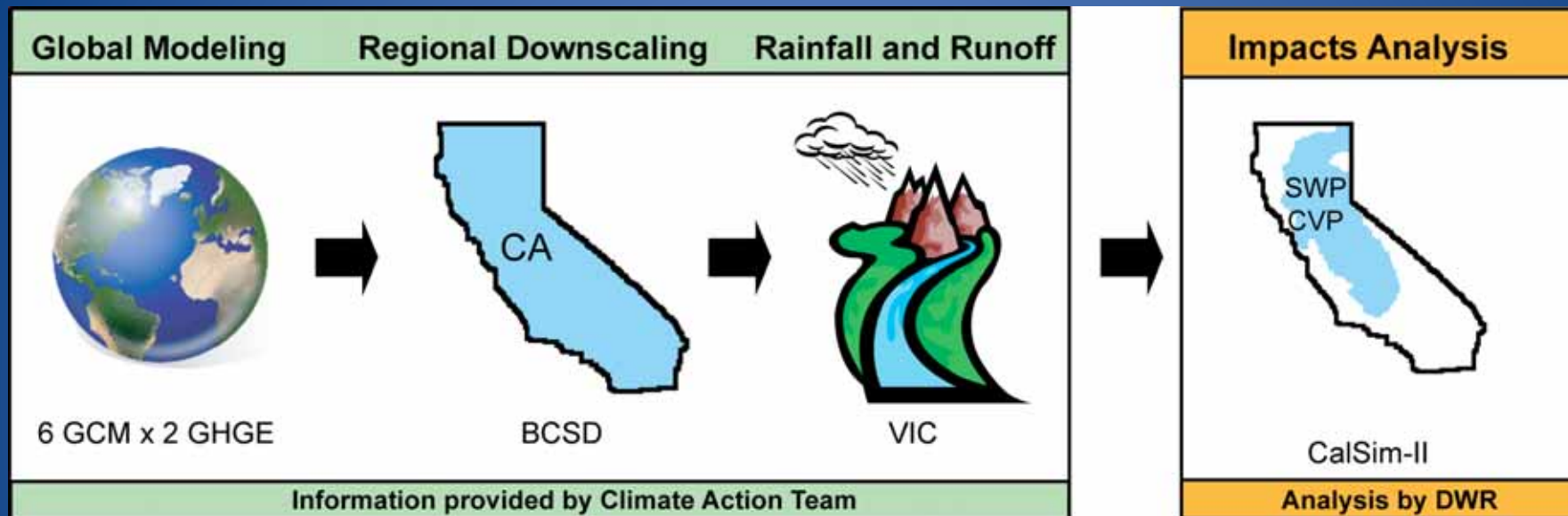
A 4°C increase in air temperature shifts 50% inflow from mid-March to mid-Feb

Runoff in April to July



SWP-CVP Impacts

SWP-CVP Impact Assessment Methodology



- Delta exports (supply)
- Carryover storage
- Groundwater pumping
- X2 location (environment)
- Vulnerability to System Interruption (reliability)

CALSIM II Grid

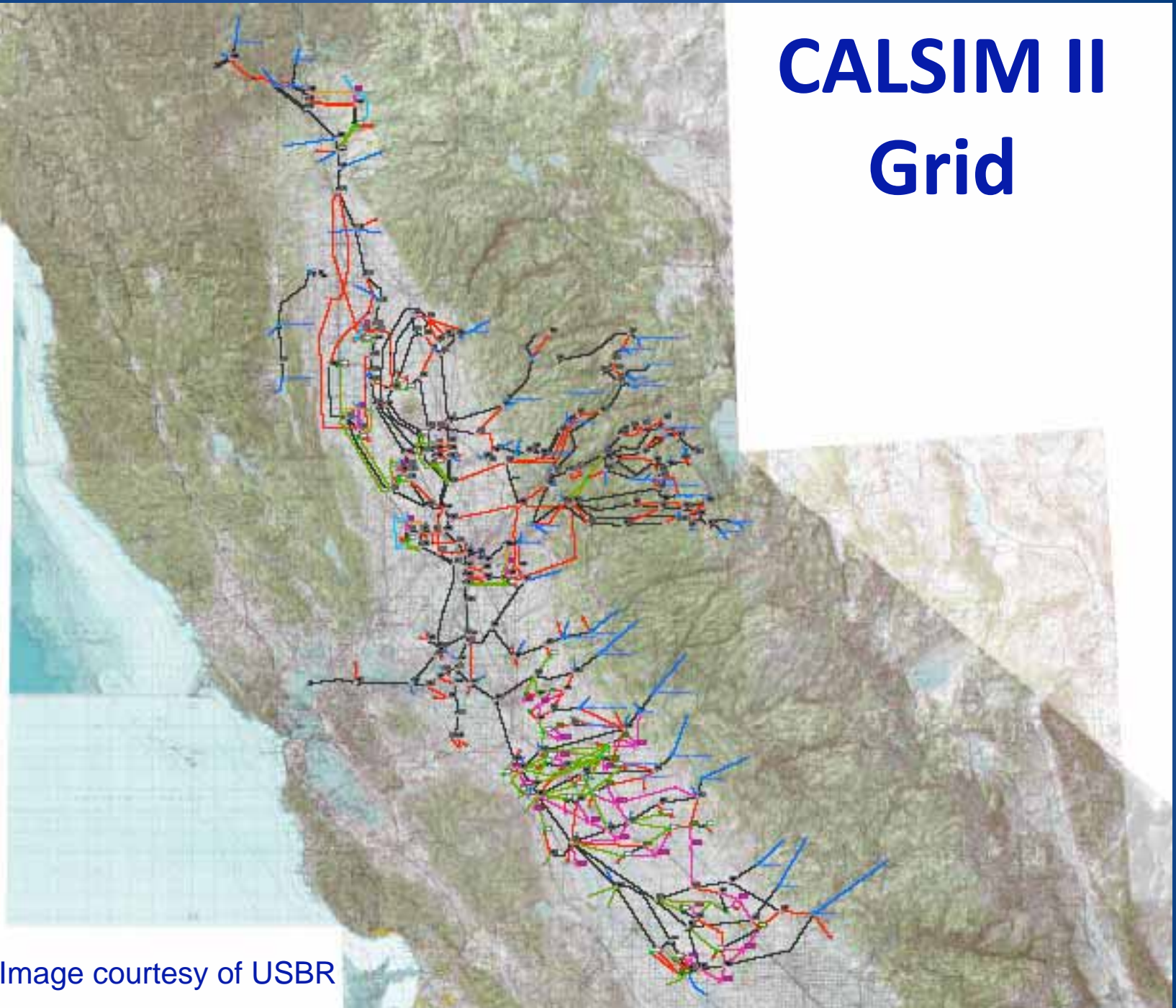


Image courtesy of USBR

DSM2 Grid

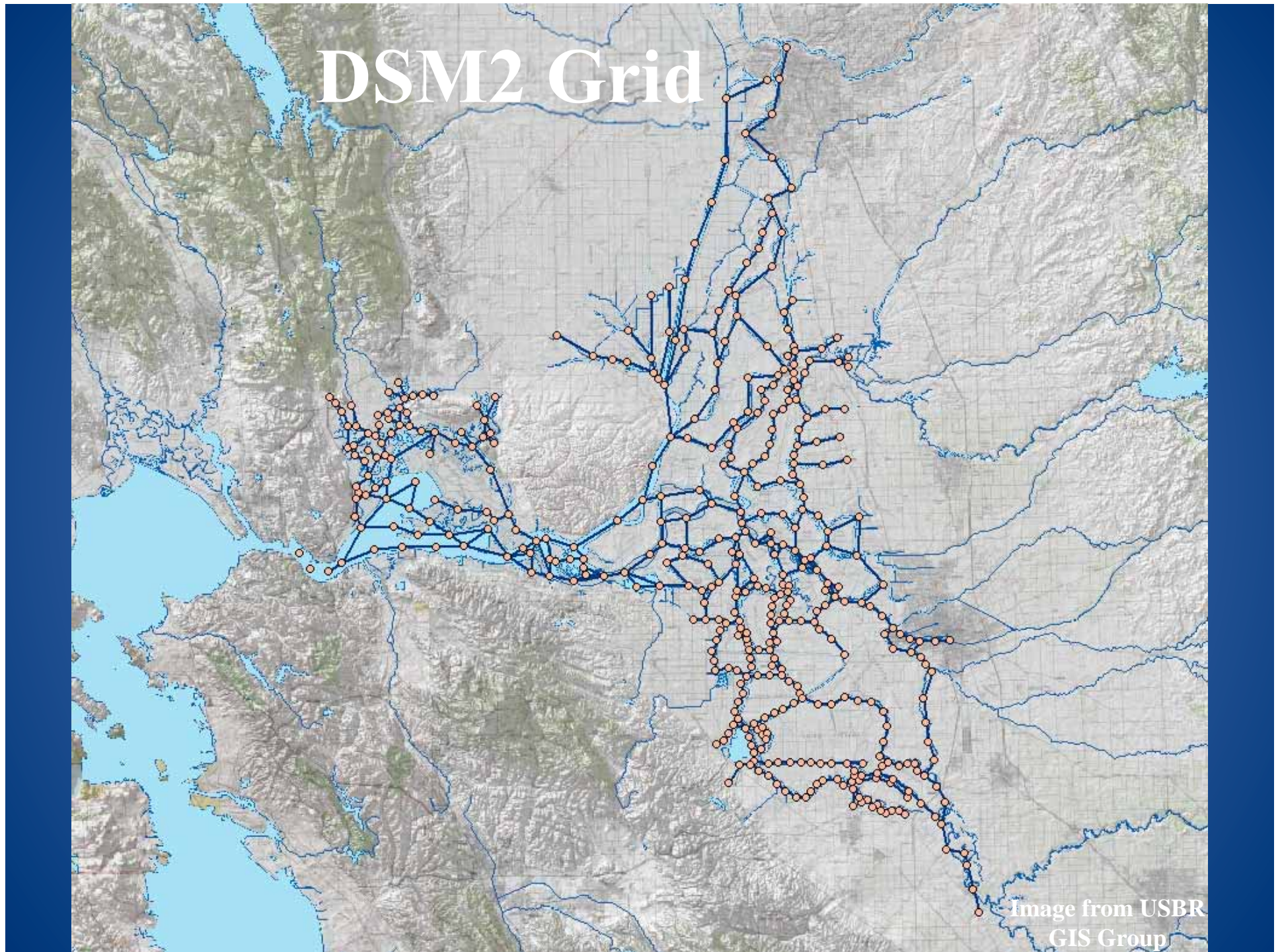
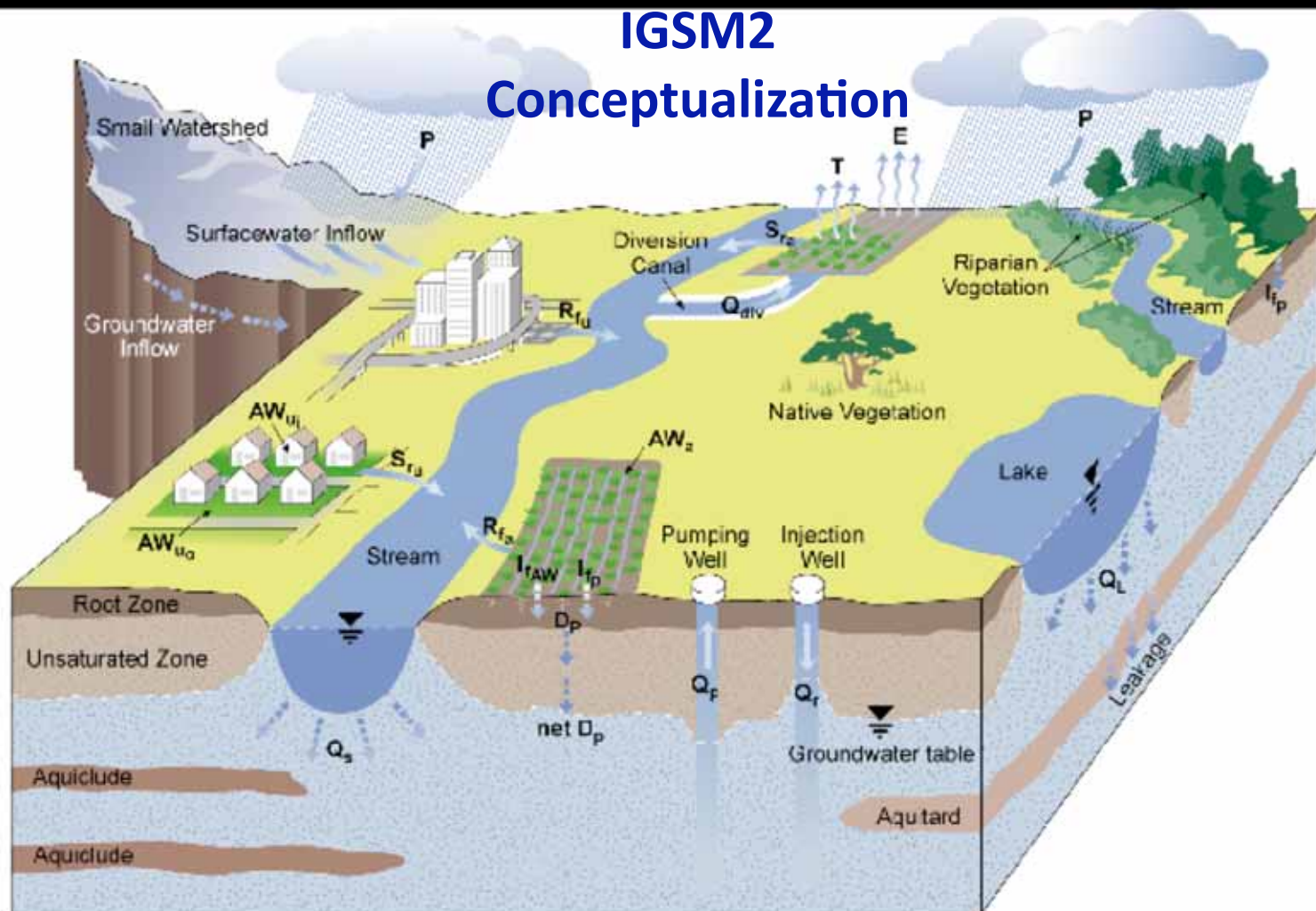


Image from USBR
GIS Group

IGSM2 Conceptualization



LEGEND

P Precipitation

AW_a Water applied to agricultural lands

AW_{ui} Water applied to indoor urban lands

AW_{uo} Water applied to outdoor urban lands

E Evaporation

T Transpiration

I_{fp} Infiltration of precipitation

I_{fAW} Infiltration of applied water

Q_{div} Surface water diversion

S_{ra} Agricultural runoff

S_{ru} Urban runoff

R_{fa} Agricultural return flow

R_{fu} Urban return flow

D_p Deep percolation of water to the unsaturated zone

$net D_p$ Recharge to the groundwater aquifer

Q_p Pumping from groundwater aquifer

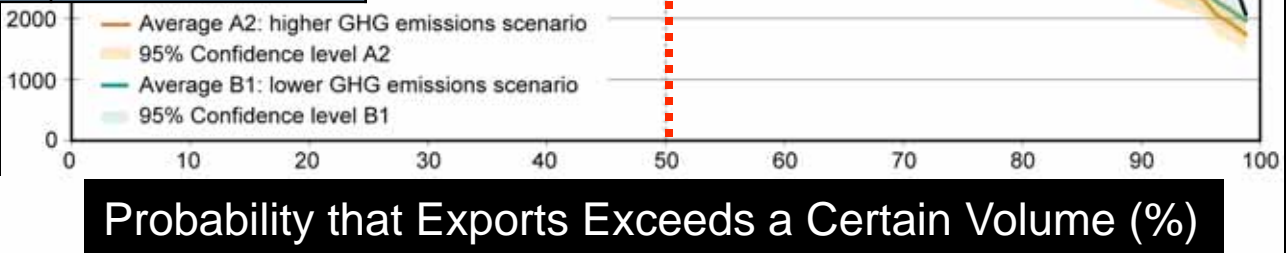
Q_r Recharge to groundwater aquifer

Q_s Stream-groundwater interaction

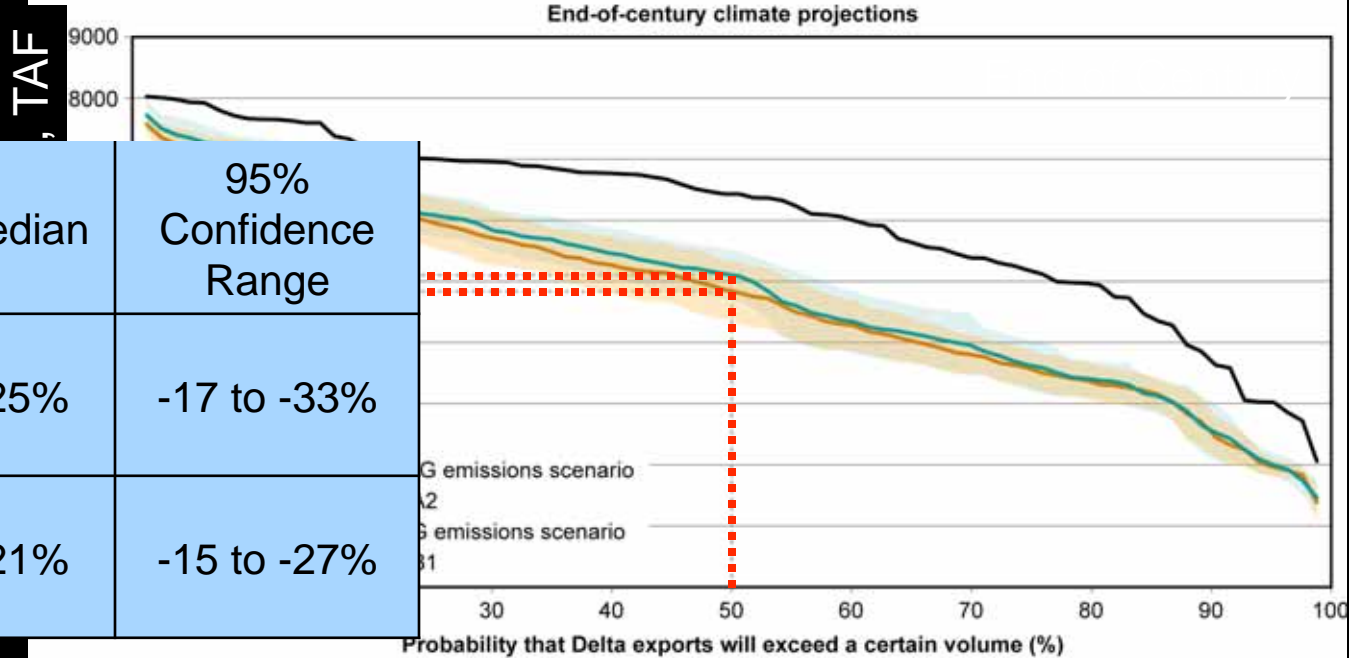
Q_l Lake-groundwater interaction

		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	-10%	-3 to -18%
	Lower GHGE (B1)	-7%	0 to -16%

Annual
Delta
Exports



		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	-25%	-17 to -33%
	Lower GHGE (B1)	-21%	-15 to -27%



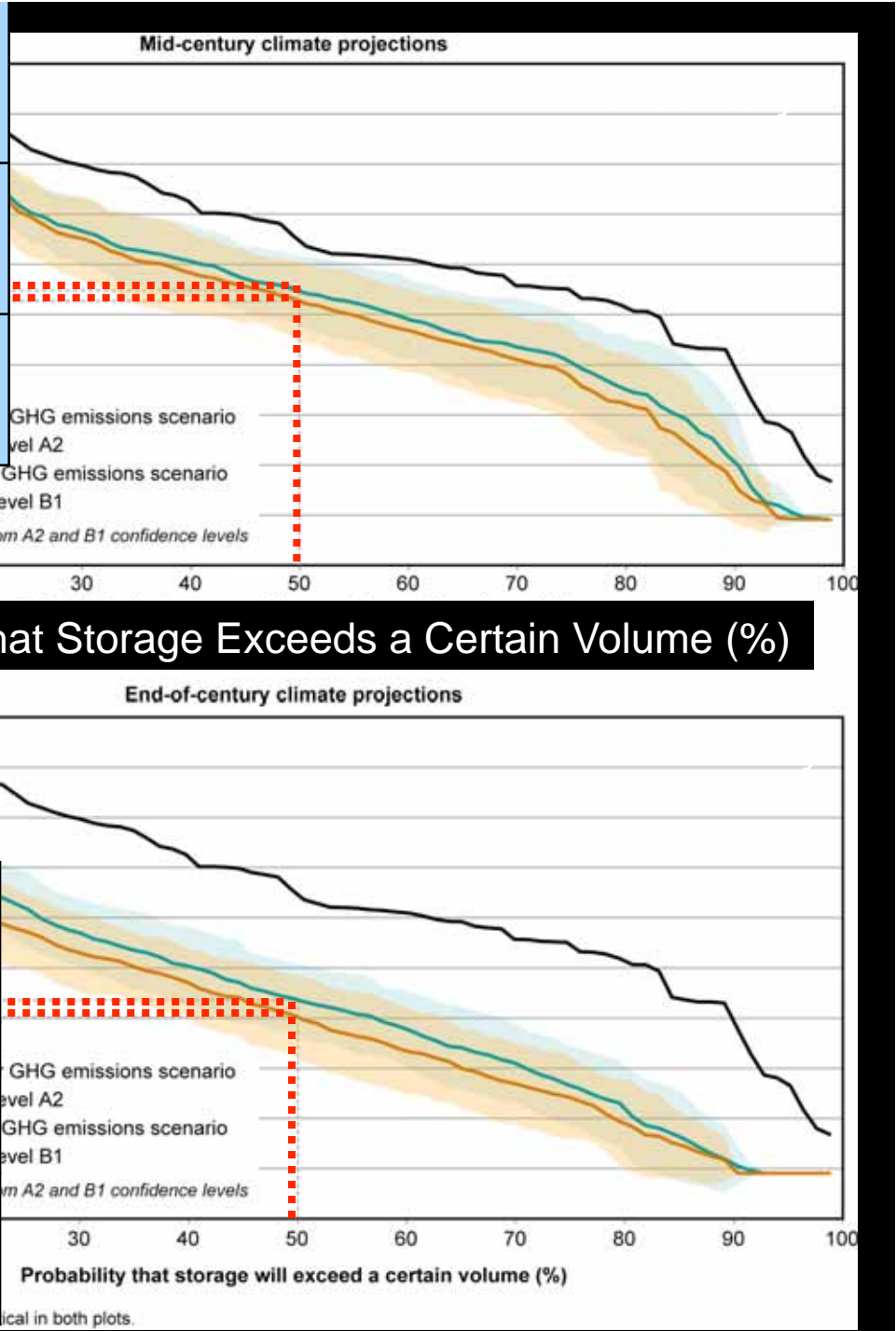
		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	-19%	-6 to -31%
	Lower GHGE (B1)	-15%	-3 to -26%

Reservoir Carryover Storage

Carry

TAF

		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	-38%	-24 to -51%
	Lower GHGE (B1)	-33%	-21 to -45%

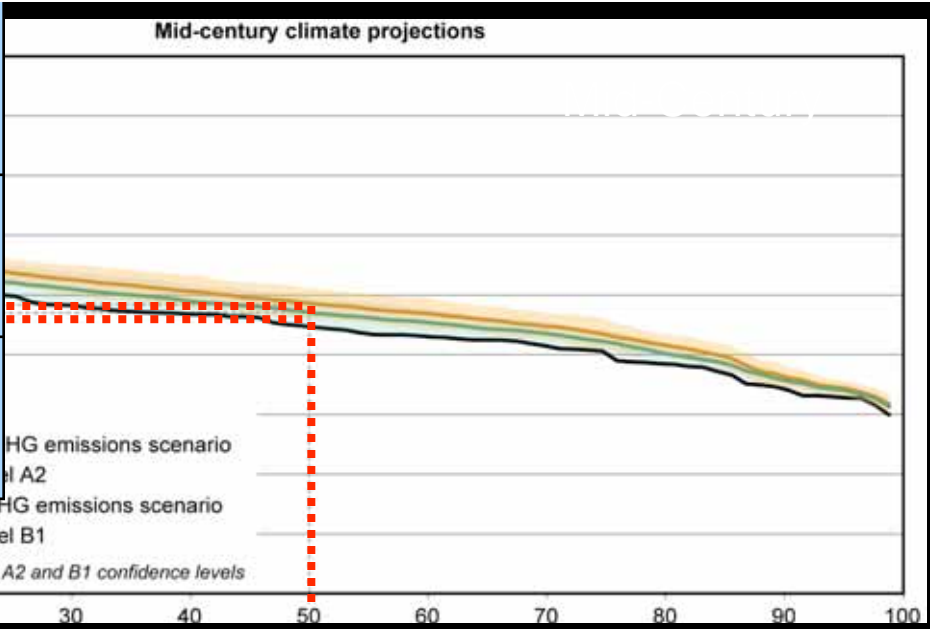


		Median	95% Confidence Range
Mid-Century	Higher GHGE (A2)	+9%	+2 to +15%
	Lower GHGE (B1)	+5%	-2 to +11%

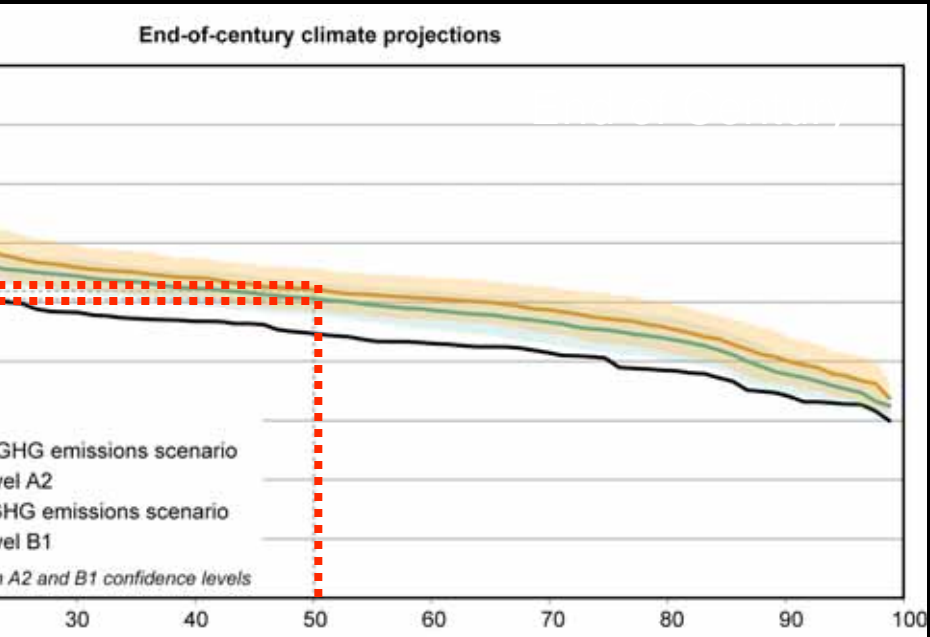
Sac Valley Groundwater Pumping

Pumping, TAF, Ground

		Median	95% Confidence Range
End of Century	Higher GHGE (A2)	+17%	+7 to +24%
	Lower GHGE (B1)	+13%	+7 to +18%

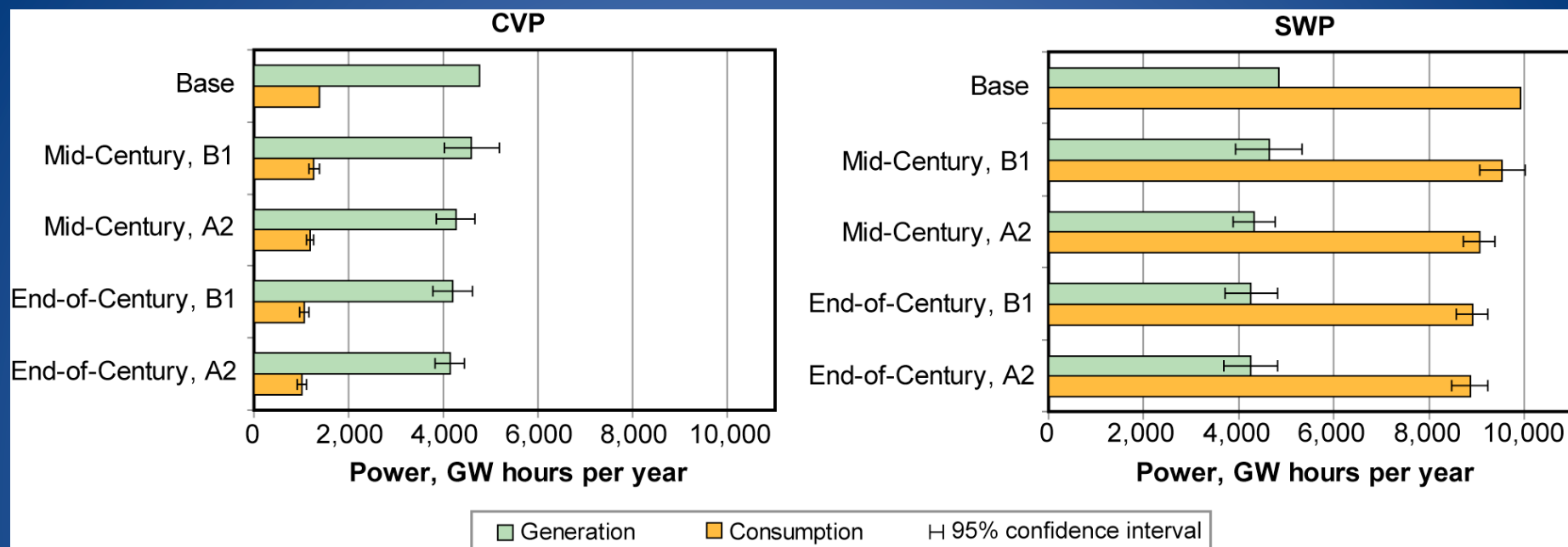


Probability that GW Pumping Exceeds a Certain Volume (%)



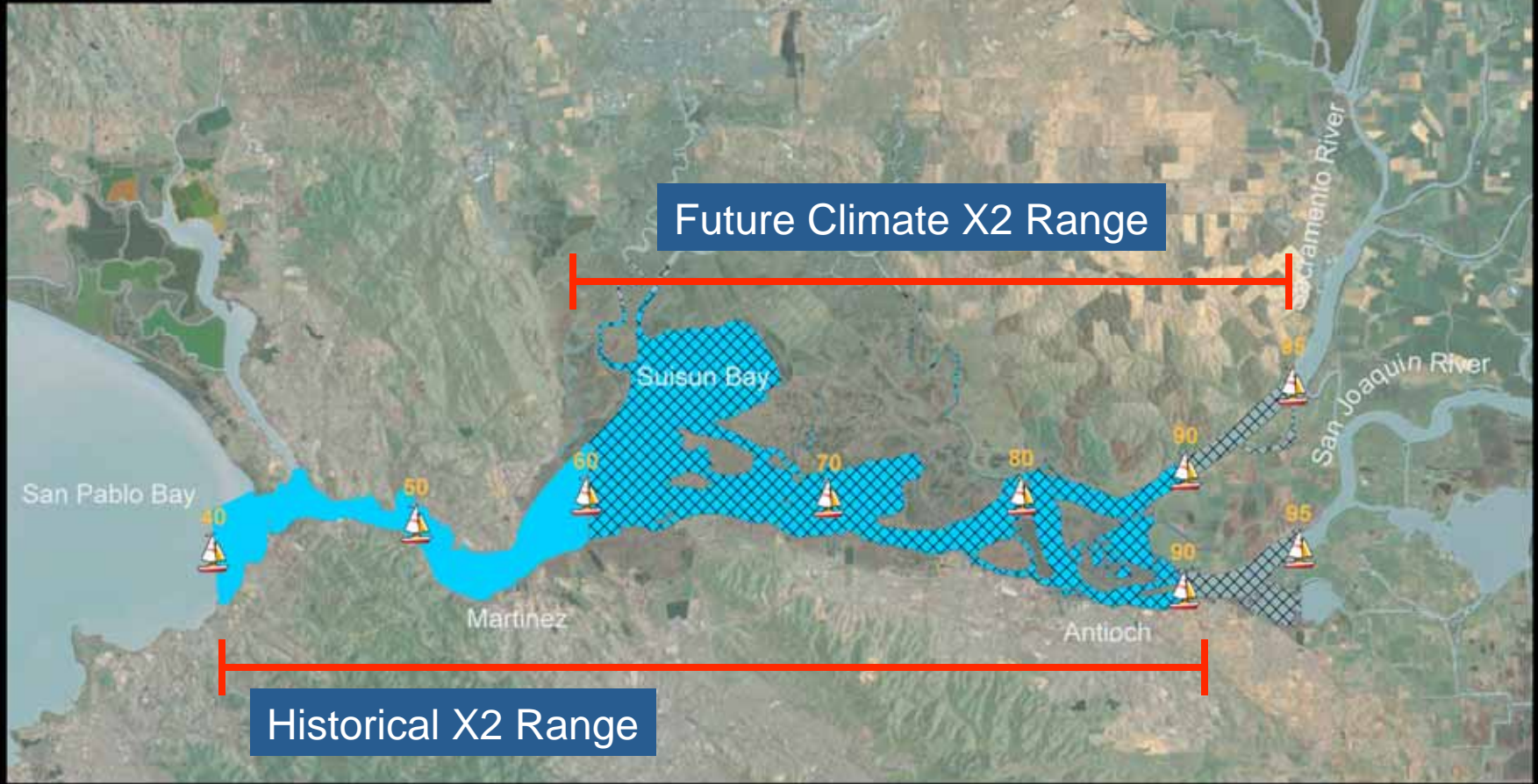
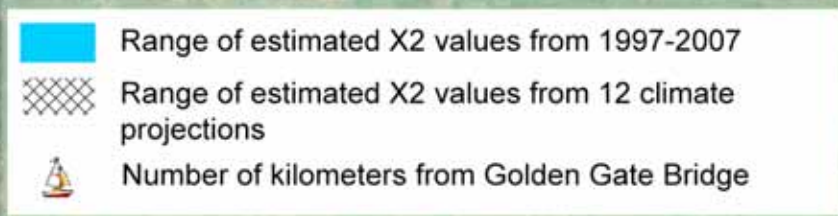
Probability that pumping will exceed a certain volume (%)

Power Supply



	Mid-Century		End of Century	
	Higher GHGE (A2)	Lower GHGE (B1)	Higher GHGE (A2)	Lower GHGE (B1)
CVP Gen.	-11%	-4%	-13%	-12%
CVP Use	-14%	-9%	-28%	-24%
SWP Gen.	-12%	-5%	-16%	-15%
SWP Use	-10%	-5%	-16%	-16%

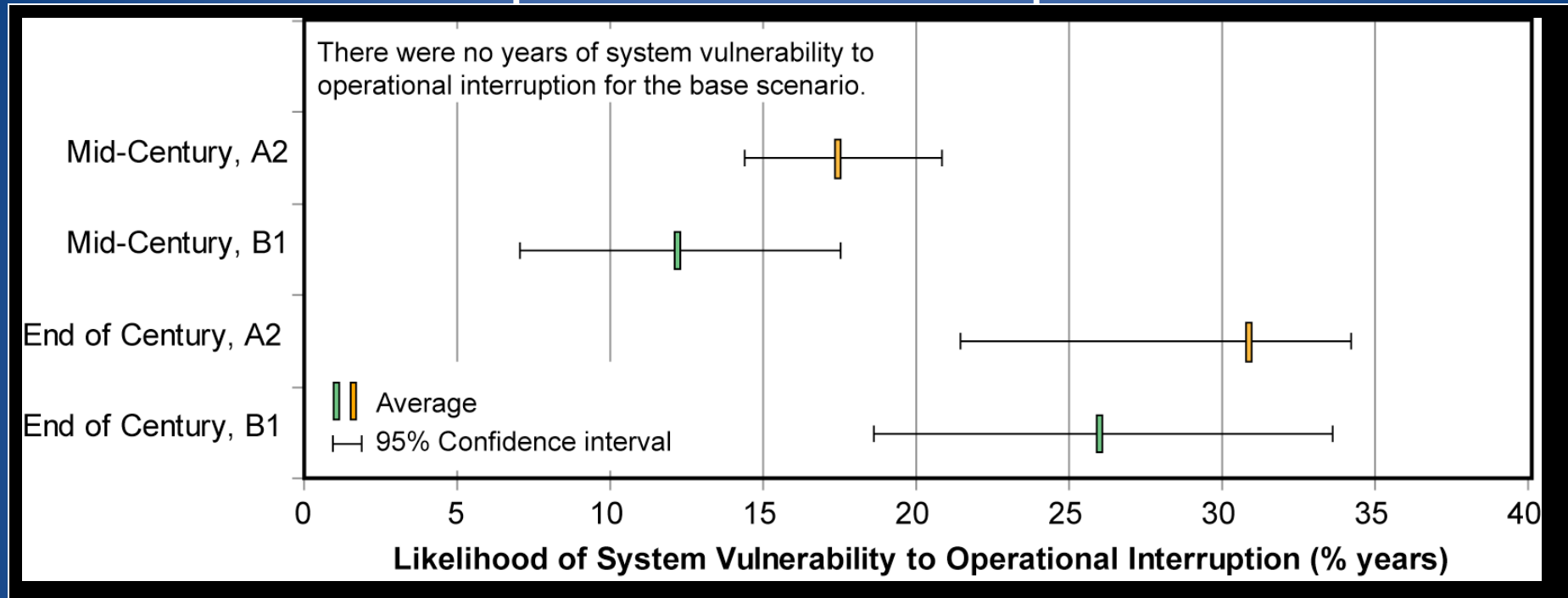
X2 Position



System Vulnerability to Operational Interruption

- The SWP-CVP system is vulnerable to operational interruption when water levels go below the lowest outlets (dead storage) in at least one of the main storage reservoirs
 - Trinity, Shasta, Oroville, and/or Folsom

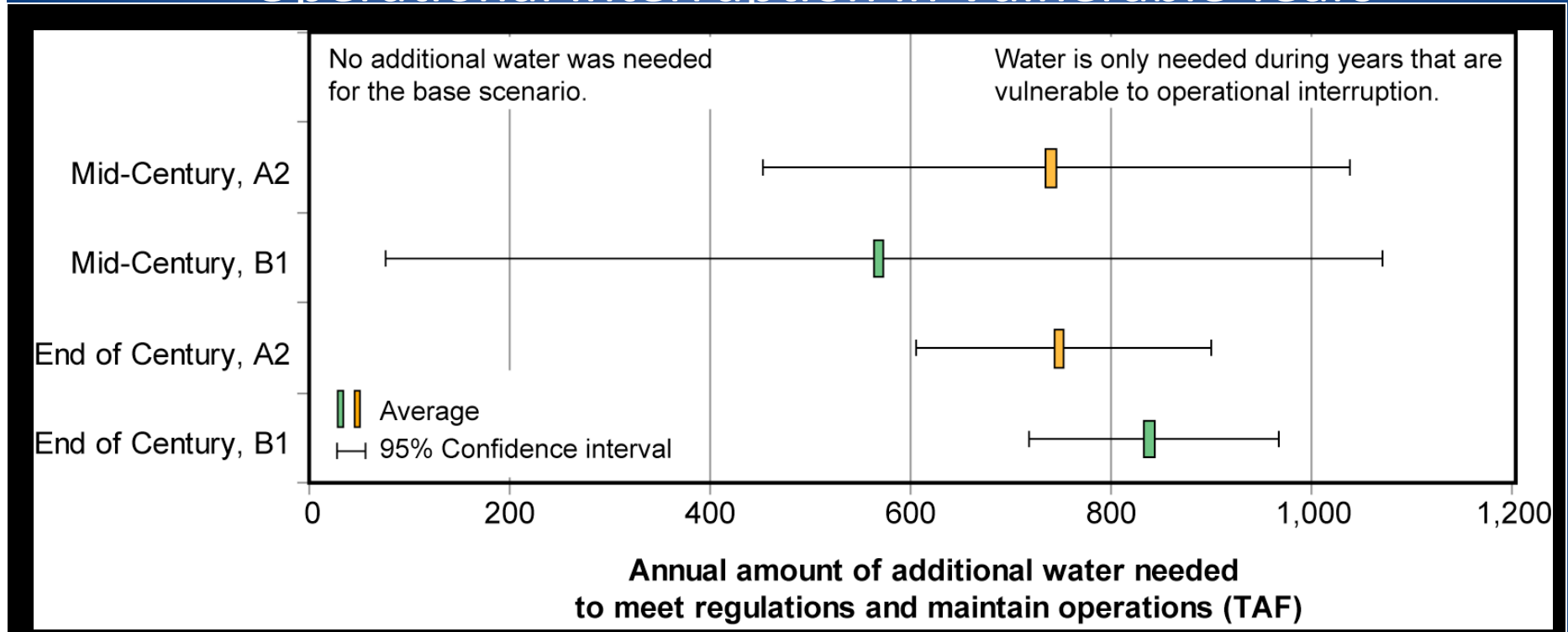
SWP-CVP Vulnerability to Operational Interruption



At mid-century 1 in 6 years is vulnerable for A2
1 in 8 years is vulnerable for B1

**By the end of the century 1 in 3 years is vulnerable for A2
1 in 4 years is vulnerable for B1**

Amount of Additional Water Needed to Avoid Operational Interruption in Vulnerable Years



At mid-century 750 TAF is needed in vulnerable years for A2
575 TAF is needed in vulnerable years for B1

By the end of the century 750 TAF is needed in vulnerable years for A2
850 TAF is needed in vulnerable years for B1

Take Home Message



- Sea level rise
 - Amount, probability, Delta salinity ANNs
- Effects of increasing air temp on Feather basin
 - ↓ April snowpack, ↓ runoff in April-July
 - ← 50% inflow to Oroville up to a month earlier
- Effects of climate change on SWP and CVP
 - ↓ annual Delta exports, ↓ reservoir carryover storage
 - ↑ annual groundwater pumping
 - → X2 range moves upstream, standard still met
 - ↓ Power supply
 - ↑ vulnerability to operational interruption



www.climatechange.ca.gov
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